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The Value of a Statistical Life in the context of Earthquakes: an approach from Prospect Theory

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Abstract

In this article we replicate the method developed by Carthy et al (1999) to obtain the Value of a Statistical Life chaining the estimates from a Contingent Valuation survey on non-fatal injuries and a Relative Utility Loss ratio derived from Lottery Equivalent questions to subjects. The novelty of our work stems from applying this methodology to the context of Earthquakes and introducing non-linear probability weighting to subjects' responses. Changing the context of the questionnaire should change the values obtained for a Statistical Life as stated in the literature and introducing a probability weighting function should be of interest to potentially remediate previous internal consistency issues regarding the "direct" and the "indirect method", two variations that should theoretically give equivalent results but that have yielded way too diverging estimates in previous studies, raising concerns on the validity of the method. Our results show a significant reduction in the divergence of the results from the direct and the indirect method.

Keywords: Value of a Statistical Life, Earthquake, VOSL, Prospect Theory, Chained Approach

Table of Contents

1. Introduction

The Value of a Statistical Life is the cost that a person would be willing to bear for an increase of safety that would decrease his risk of death such that, aggregating the results of the inquired sample, the expected number of fatalities would be reduced by one.

Hence, this term does not involve the valuation of a life, but the valuation of reductions in the risk of death. This concept is of utmost importance in the context of safety, more specifically for public sector cost-benefit analysis, for which there have been traditionally two approaches to obtain such value.

One is based on revealed preferences, and is based on empirical estimates stemming from data about actual choices involving trade-offs of wealth for risk. This approach is typically, but not exclusively, applied to labor markets (Viscusi and Aldy, 2003; Viscusi, 2018).

The other one is the Contingent Valuation (CV) approach. Through this, members of a representative sample of the population at risk are asked about their Willingness to Pay (WTP) for a small hypothetical reduction of such risk, and the Willingness to Accept (WTA) for an increase in it.

This second approach follows the prescriptive premise that the public sector should take into account the preferences of the population affected by the respective decisions from policy-makers. This way of valuating safety is the one employed by the UK Treasury and the US Department of Transportation among others and the applications of this approach have mainly consisted on health risks, road safety and environmental risks contexts (Viscusi and Masterman, 2017).

Increasingly, it is becoming evident that the values assigned to safety based on WTP and WTA are not universally applicable. Instead, people's pre-existing willingness to pay in order to mitigate risks tends to differ based on their individual perceptions of various hazards. Factors influencing these differences include perceiving the hazard as voluntary or not, the level of control the potential victims have over it, if some personal responsibility is considered or the extent to which the event is well-understood, among other reasons.

According to the findings of McDaniels et al. (1992), the extent to which individuals are willing to pay to mitigate risks is mainly influenced by the perceived exposure to the hazard in the case of familiar and well-defined risks, for instance car and airplane accidents. However, for those dangers that are less familiar and poorly understood (e.g. nuclear power), the key factors significantly impacting WTP answers are the levels of "dread" associated with the hazard and the perceived severity of the negative outcomes.

With this in mind, in this article we want to elicit the Value of a Statistical Life in the context of an earthquake, using the method developed by Carthy et al (1999), which was applied to health risks in a road safety context.

Earthquakes are becoming an event of increasing relevance due to climate change. This year, over 50.000 people lost their lives in Syria and Turkey due to an earthquake. The bad conditions of buildings and infrastructure was brought to the forefront, since a better preparation against such catastrophe would have saved many of those lives. Thus, the importance of investments on safety improvements in the context of earthquakes has become even more prominent these days.

Though in Spain strong earthquakes are not frequent, this does not mean this contingency should be ignored. In 2011, Lorca, a spanish municipality of around 90.000 people, was hit by a devastating seism (5.1 degrees in the Richter scale) that caused the death of 9 people, over 300 neighbors were injured, a total of 33.000 families were affected and 1.700 homes were destroyed. Hence, we think safety improvements for this kind of events should also be taken into account in Spain, where we conduct our study.

Also, we introduce a novel approach in the measurement of the VOSL. We weight the values obtained for the probabilities with a non-linear function, a classic feature from Prospect Theory that we think can introduce relevant changes in the estimations, given the more accurate descriptive analysis of human behavior provided by this theory with respect to Expected Utility Theory. To our knowledge, this is the first attempt to introduce it for the estimation of the Value of a Statistical Life.

2. The Method

The theory on the valuation of a Statistical Life indicates that the estimation of the Marginal Rate of Substitution (MRS) between wealth and the risk of death can be accomplished through the valuation of both Willingness to Pay (WTP) and Willingness to Accept (WTA) (Jones-Lee, 1974). However, a relevant challenge faced when using this approach is that individuals have to assign a value to extremely small variations in risk, as this reflects the actual risk of death in a car accident. Nevertheless, there is abundant evidence indicating that Contingent Valuation (CV) methods are susceptible to issues of scope insensitivity, as highlighted by Beattie et al. (1998) and Hammitt and Graham (1999), that is, people are not able to accurately describe the value they attach to very small changes in probability.

To overcome this issue, Carthy et al. (1999) developed a method, the CV/SG Chained Approach, where they did not ask directly for such small variations in probabilities. The subjects in their experiment found it indeed much more manageable to reply to their valuation questions than in previous experiences with the traditional direct CV approach.

The CV/SG Chained Approach consisted of the following steps to obtain the Value of a Statistical Life:

1. Estimating the Willingness to Pay and the Willingness to Accept from the subjects for a certain non-fatal injury (in this case, caused by the earthquake), which allows to compute the Marginal Rate of Substitution of wealth on the injury through different specifications of the utility function (we will use 2 of them).
2. An MSG (Modified Standard Gamble) question, where respondents have to state the probability for which they are indifferent between two (risky) treatments. Namely, Treatment A = (*p, Death; Injury I*) and Treatment B = (*q, Death; Normal Health*), with p given based on experts' advise. With this information (p and q), a ratio denominated by Carthy et al as Relative Utility Loss can be computed, which is equivalent to the ratio between the MRS of wealth on death (m_d) over the MRS of wealth on Injury I, (m_i). More specifically, they show that:

$$\frac{m_d}{m_i} = \frac{1-q}{p-q}$$

   The authors assume people are Expected Utility Maximizers. Hence, this part of the method would yield different results under Prospect Theory.

3. With the results from steps 1. and 2., we can estimate m_d chaining:

$$m_d = \frac{1 - q_i}{p_i - q_i} \times m_i$$

without asking participants any CV questions about very small risk reductions.

Carthy and coauthors also introuced a variation of this method. If the steps that were just presented conformed the so-called direct chaining method, they introduced an indirect method as well.

1. They elicited the MRS of wealth on Injury J, which was a less severe injury than Injury I used for the direct method. They do this asking WTP and WTA questions.
2. The MSG question this time presents two lotteries that are different to the previous ones, namely C = (*θ, Injury I; Injury J*) versus D = (*π, Injury I; Normal Health*). From this, and similarly to the direct approach, we can estimate m_i :

$$m_i = \frac{1 - \theta_j}{\pi_j - \theta_j} \times m_j$$

3. Then, we can chain:

$$m_d^{ind} = \frac{1 - q_i}{p_i - q_i} \times \frac{1 - \theta_j}{\pi_j - \theta_j} \times m_j$$

This m_d obtained through the indirect method should be equal to the one obtained for the direct method, but in their study, Carthy et al get a much larger value for the indirect computation. This is probably the major issue they face in their paper, since this raises concerns about the internal consistency of estimating the VOSL this way.

Sánchez-Martínez et al (2021) argue that this divergence might be due to too low values in the denominator in the Right Hand Side of the following expression

$$\frac{m_i}{m_j} < \frac{1 - \theta_j}{\pi_j - \theta_j}$$

That is, the Relative Utility Loss derived for the two injuries is not equivalent to the ratio derived through the elicited probabilities, and one potential reason might be that respondents are not willing to bear barely any additional risk under Treatment D with respect to C, such that this ratio becomes too large. They base this argument on the fact that in the original study by Carthy et al, 10% of their sample did not want to accept any additional risk and that the median risk in the lottery where death was the worst outcome was very small (about 1%).

Given the importance that Sánchez-Martínez and coauthors endorse to the values obtained for the probabilities, we think a feature of Prospect theory like probability weighting can play a significant role as for the divergence between the direct and indirect method, which, as said, can be regarded as the major reason for concern when applying the CV/SG chained approach.

3. Applying non-linear probability weighting

In previous experiments the results obtained through the presented indirect method yield way too high results for the VOSL compared to those from the direct method, when theoretically, they should give the same value.

As previously commented, Sánchez-Martínez and others related this phenomenon to the low values obtained for the probabilities from the Modified Standard Gamble questions. There is extensive evidence that people tend to perceive small probabilities as higher than they actually are. Hence, in this context, their statements will show a lower willingness to bear any additional risk than their true one, that is, we are possibly missing a real value of the RUL that is smaller than the one we receive from the questionnaire.

In order to correct for this bias, we can make use of one of the main concepts introduced by Kahneman and Tversky (1979): non-linear probability weighting.

Also a reference point needs to be fixed for the analysis. MaxMin as a reference point was introduced by Hershey and Schoemaker (1985). According to this principle, when comparing two prospects, people tend to focus on the worst possible outcomes of each option and consider the maximum of these as their benchmark. This will represent the guaranteed amount they can obtain.

Assuming MaxMin as a reference point, which has been shown to be the reference for a high share of experimental subjects in the literature (check for instance Baillon et al., 2020), death becomes the reference point in the first MSG question (Treatment A = *(p, Death; Injury I*) vs Treatment B = (*q, Death; Normal Health*)) and the more severe Injury

I in the second MSG question (Treatment C = (*θ, Injury I; Injury J*) vs (*π, Injury I; Normal Health*)), since they are the worst possible outcome included in each of the two mixed prospects for their respective MSG question, which implies they can be taken by subjects as their reference points as shown by Baillon et al. (2020).

Taking in this case the worst outcome as the reference point justifies analysing the responses to our MSG questions only in the gains domain. Hence, we introduce a non-linear function for the probabilities p and q in the RUL expression for the direct method, and also for θ and π.

The weighting is derived more specifically through the two-parameter functional form introduced by Goldstein and Einhorn (1987):

$$w(p) = \frac{\delta p^{\gamma}}{\delta p^{\gamma} + (1-p)^{\gamma}}$$

Where δ > 0 stays for the elevation of the weighing function and γ > 0 measures its degree of curvature. Ideally these two parameters would be obtained from the sample studied, but for simplicity we take them from the literature, from Tversky and Fox (1995), given the resemblance with our design.

Then applying this function, our RUL expression becomes:

$$\frac{m_d}{m_i} = \frac{1 - w(q_i)}{w(p_i) - w(q_i)}$$

We expect this RUL to be smaller than under Expected Utility for two reasons. First, if small probabilities are overweighted, the numerator will be smaller. Second, non-linearity of the function may lead to a bigger difference between p and q (and between θ and π) expressed in the denominator, if they are small enough. Hence, a bigger denominator would lead to a smaller RUL.

As a consequence of this, a smaller RUL will imply a lower VOSL as well. For the same reasons, we also expect a reduction of the RUL for Injury I over Injury J (m_i/m_j), thus, chaining the two RULs under Prospect Theory should lead to a smaller VOSL for the indirect method than under Expected Utility Theory, potentially reducing the divergence with respect to the direct method.

4. The VOSL main study

4.1 Design of the questionnaire

22 subjects were chosen to respond the questionnaire. The sample is comparable to the usual convenient sample of students used for lab experiments, since all of them are studying at the University.

At the beginning of the questionnaire, the reader is presented a story in which she is involved in an earthquake happening in Lorca, Murcia, with the purpose of putting them in a realistic context that they could relate to.

Subjects are first presented with a set of 4 injuries of diverse severity, describing the duration of the treatment and the consequences for their health and well-being. The only purpose of this step is to familiarise them with the different severity of the injuries.

The injuries were:

- A granite block hits your head, you spend weeks in hospital and suffer permanent brain damage.
- You fracture both legs as a result of a detachment caused by the earthquake: 2 to 3 weeks in hospital, with severe to moderate pain. When you leave the hospital, you continue with pain and discomfort for weeks or months, as well as work and leisure restrictions. You recover fully after 18 months.
- You fracture a foot due to a detachment caused by the earthquake: 2 to 3 days in hospital with moderate pain. When you leave the hospital, you continue with pain and discomfort for weeks, as well as work and leisure restrictions. You recover fully after 3 to 4 months.
- You fracture a few fingers on your hand: you spend 1 day in hospital, you have some pain, in 1 to 2 months you are fully recovered.

Then came the Contingent Valuation. Carthy et al presented Injury I and Injury J as two injuries of different severity (more and less severe respectively), simply by describing the pain and treatment required, but avoiding to specify any particular type of injury. However, we decided to picture the injuries as a fracture of both legs (I) and a fracture of a foot (J), hoping this would help to reduce to some extent the hypothetical bias and helping subjects to put themselves in the situation and give more accurate answers as for their WTA and WTP.

Then they were asked about their WTA for a non-fatal fracture of the two legs. Similarly to the original study, they were introduced to a situation where they win the lottery on the same day as they get injured, and they should classify the potential amounts of money for the prize into “definitely enough”, “not sure” and “definitely not enough” in the sense of what would make that day “not a good nor a bad day”, and then write down a specific amount that had to belong to the range between the lowest amount in “definitely enough” and the highest amount in “definitely not enough”. This is their WTA for the injury.

As for the WTP, since in Spain most people attend free-of-charge public hospitals to treat their injuries, we considered a story in the same line as the original paper, where the standard treatment (available under the public system) would result in the prognosis specified on the respective injury description and then asked about their Willingness to Pay for a non-standard treatment (at a private hospital) that would result in a return to normal health within 3–4 days and avoiding all the inconveniences related to the injury

We repeated the procedure for the less severe injury consisting in the fracture of one foot. We made sure to repeat the description of the injury as for the prognosis and consequences of the treatment.

Knowing the WTA and the WTP, we could obtain the Marginal Rate of Substitution of wealth on the respective injury for different specifications of the utility function for wealth. From the previous literature, we restricted our attention to the logarithmic and the homogeneous functions. The expressions derived for the MRS of wealth on injury for the two specifications turn out to be:

1. logarithmic specification: $$m_i = (\frac{\hat{x}\hat{y}}{\hat{y} - \hat{x}}) ln \frac{\hat{y}}{\hat{x}}$$
2. homogeneous specification: $$m_i = (\frac{2\hat{x}\hat{y}}{\hat{x} + \hat{y}})$$

with $\hat{x}$ = WTP and $\hat{y}$ = WTA.

As for the second step of the method, the Modified Standard Gamble question was provided by presenting them two possible treatments. Treatment A, which if successful led to the prognosis related to the fracture of the two legs, but if unsuccessful (with probability p), led to death; alternatively, Treatment B, if successful led to complete health, but if unsucessful (with probability $q > p$), led to death. Probability p was fixed by experts at 1 over 1000 in the experiment of Carhty et al. Given the prognosis described for the more severe injury in their paper and after we asked for advise to some doctors, the fracture of two legs seems a plausible example for Injury I.

Subjects had to state a probability q (bigger than p) for which they would be indifferent between the two treatments.

Knowing the value of p and q, we could derive the Relative Utility Loss.

Knowing the MRS of wealth on the fracture of the two legs and the Relative Utility Loss, we can compute the Marginal Rate of Substitution of wealth on death for each subject and then derive the Value of a Statistical Life for the whole sample.

In our case, following what Carthy and his coauthors deem the best estimates for policy recommendations, we obtain the VOSL estimating the trimmed mean (that is, ignoring outliers) and the median. This gives us the estimation through the direct method.

For the indirect method, we use the answers for the WTA and WTP questions for the fracture of a foot, introduced in the same framework and story as previously described for the more severe injury. Then, the MSG consisted of Treatment C, which if successful led to the prognosis associated to the fracture of a foot, but led to the fracture of the two legs with probability θ; and Treatment D, that if successful supposed the recovery of complete health, but with probability π (bigger than θ) led to the fracture of the two legs. θ was set at 1 over 100.

In this case, chaining the MRS of wealth on the fracture of one foot, with the RUL from the first MSG and with the RUL from the second MSG results in the MRS of wealth on death obtained through the indirect method (exactly as introduced in the methodological section of this article for Injury J). again, estimating the trimmed mean and the median, we get the Value of a Statistical Life.

If we want to change our framework to Prospect Theory, we can derive the same RUL expression, only this time using the probability function by Goldstein and Einhorn for each and every subject.

This will vary the Relative Utility Loss and hence the results for the direct method, but also for the indirect method.

4.2 Main study results

4.2.1 Summary statistics

In Table 1 we show some of the results from our experiment: WTA and WTP for both non-fatal injuries, and the probabilities *q* and *π* to be indifferent between Treatment A and B and between C and D respectively, as well as their weighting.

Table 1: Summary statistics of the 22 respondents (WTA and WTP in euro)

Variable	Mean	Median	Standard Error
WTA for I	143.022,73	50.000,00	47.243,50
WTP for I	37.556,82	10.000,00	22.251,78
WTA for J	16.036,36	7.500,00	4.963,85
WTP for J	7.809,09	2.250,00	4.445,29
q	0,0222	0,0035	0,0074
π	0,0536	0,0400	0,0107
w(q)	0,0416	0,0150	0,0104
w(π)	0,0880	0,0785	0,0117

From the Contingent Valuation results sensitivity to scope can be remarked, since the mean WTA and WTP for I (meaning the fracture of both legs) are higher than the mean WTA and WTP for the less severe injury J respectively. This sensitivity to scope can be found for all subjects but one, who stated a higher WTP for the fracture of the foot than for both legs (3000 euro against 2000). Also there were no zero bids for any of the WTP responses and there was always some finite sum for the WTA questions.

4.2.2 The VOSL for earthquake risks

Estimates of the value of a statistical life are shown in Table 2 for the logarithmic utility function and in Table 3 for the homogeneous. These specifications work under the assumption that WTA > WTP.

There were 4 subjects who were not open to take any higher risk of death under Treatment B than under A (*q*=0,001), nor under Treatment D with respect to C (*π* =0,01). This means for them $\frac{m_d}{m_i} \rightarrow \infty$ and $\frac{m_i}{m_j} \rightarrow \infty$, thus, their responses were ommited when obtaining the trimmed mean of the MRS of wealth on death m_d, both under the direct and indirect method, but not for the median value of m_d.

There was another subject choosing π = 0,01, though she was accepting some extra risk of death under Treatment B, hence her answers were trimmed out only in the application of the indirect method.

For the respondents stating a WTA equal to WTP, we do not regard their results since for them WTA = WTP = m_d, instead of any of the 2 functional forms considered. This happened once for the more severe injury and three times for the less severe injury.

Table 2: VOSL estimates for the logarithmic utility function (in euro)

Method	Trimmed Mean	n*	Median	n**	Std Error
Under Expected Utility					
Direct Method	8.330.876,13	15	3.317.947,45	17	3.330.731,10
Indirect Method	30.777.526,64	12	80.572.883,68	14	10.082.220,79
Divergence	22.446.650,51		77.254.936,24		
Under Prospect Theory					
Direct Method	2.343.118,71	15	1.393.670,32	17	862.596,35
Indirect Method	5.793.538,31	12	12.719.499,49	14	1.760.028,61
Divergence	3.450.419,61		11.325.829,16		

**excludes cases with q = p, π = 0, WTP = WTA and outliers*
***excludes cases with q = p, π = 0 and WTP = WTA*

Table 3: VOSL estimates for the homogeneous utility function (in euro)

Method	Trimmed Mean	n*	Median	n**	Std Error
Under Expected Utility					
Direct Method	5.748.673,04	15	2.628.947,37	17	2.230.529,81
Indirect Method	25.367.555,78	13	58.934.530,07	15	761.360,77
Divergence	19.618.882,74		56.305.582,71		
Under Prospect Theory					
Direct Method	2.180.399,51	16	1.220.893,81	17	9.224.022,86
Indirect Method	2.980.018,68	17	3.925.685,08	19	576.503,39
Divergence	799.619,17		2.704.791,27		

**excludes cases with $q = p$, $\pi = \theta$, WTP = WTA and outliers*
***excludes cases with $q = p$, $\pi = \theta$ and WTP = WTA*

Following Carthy et al., we regard trimmed means and medians as the most relevant for policy recommendations than the mean of all the data including outliers.

Our estimates of VOSL are significantly higher than others obtained through this method for road risks (check the already mentioned Carthy et al., 1999 and Sánchez-Martínez et al., 2021), however, as we commented in the introduction, the nature of the hazard involved significantly impacts the values obtained, and there is a wide range of results in the previous literature for diverse hazards and approaches in the measurement (check the report by the OECD *Mortality risk valuation in environment, health and transport policies*, 2012 or Quigley, 1998). The estimates from our experiment lie within that range.

The other result to remark is the divergence we observe between the VOSL from the direct and the indirect method. Looking at the two functional forms and for the mean and median estimates, we find this divergence is always much smaller under Prospect Theory than under Expected Utility. Thus, introducing non-linear probability weighting might serve as a partial correction for such inconsistency in the measurement of a Statistical Life.

Also, the VOSL under PT are much lower than their counterparts assuming EU. This is a direct consequence of the introduction of overweighting for the probabilities, since, as previously explained, it increases the denominator and decreases the numerator of the Relative Utility Loss ratio. The interpretation seems also reasonable. Intuitively, if people perceive small risks bigger than they actually are, their answers regarding the additional risk they are willing to bear will consist of lower values than the true ones, and consequently their Value of a Statistical Life will be exaggerated.

5. Conclusion and future research

In this article we have presented the first attempt to our knowledge to introduce some feature from Prospect Theory to the estimation of the Value of a Statistical Life. We think such modification is appropriate since this theory has been shown to yield a much more accurate descriptive analysis of human behavior than Expected Utility Theory. In this case, given the presence of small probabilities in the estimation procedure, considering the tendency of people to overweight such small probabilities seems a reasonable approach.

Our results suggest such variation can indeed contribute to overcome a central issue found in previous studies, that is, the large difference between the values obtained through the direct and the indirect method, which is very much reduced when we include a non-linear probability function.

The work we just presented can be extended in different ways. Firstly, a bigger sample could be used and, in order to obtain results from people that are familiarised with such hazard, it could be selected from a population affected by an earthquake. In 2011 there was a severe earthquake in the municipality of Lorca, Murcia, and we actually use this event to build up our story in the questionnaire to put the subjects into the situation. Performing the experiment on a sample of people that lived in Lorca during the time of the catastrophe could be an interesting attempt to measure the VOSL in such context.

As for the introduction of Prospect Theory, we take the two parameters from a comparable study, however, in future work we could obtain them from the analysed sample by introducing additional questions in our questionnaire. Also, a different reference point could be assumed such that losses would be part of the analysis, thus, introducing loss aversion and different parameters for the weighting function for losses.

Hence, there are different extensions that can be applied to this study. Be that as it may, we think the results obtained in this article constitute an encouraging first step toward future work in this direction.

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